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Fourier analysis of soft tissue facial shape in subjects with class Ⅰ malocclusion using a new software

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Abstract:
Introduction:*Orthodontic treatments can improve facial esthetics. Frontal analysis using two dimensional photographic methods fail to render appropriate analysis of the facial soft tissue shape. This study analyzed the facial soft tissue shape in relation with gender and skeletal classification using Fourier analysis.*
Methods and materials:*Photographs were taken from the frontal view of 65 adults (35 women and30 men) using stereophotography. Landmarks were identified by visual and manual examination and highlighted using a marker. All photographs were taken in NHP position. To evaluate photographs, Fourier analysis software was performed. After size normalization by setting area equal to a constant (25000 pixel), the total facial shape was analyzed.*
Results: *Some Fourier coefficients were correlated to each other. The correlation between sampled and reconstructed curves of facial shape was 99%. The mean coefficients and facial indices were similar in both sexes.*
Conclusion*: No sexual dimorphism was observed in the facial shape. Sex doesn't influence facial index.*
Keywords:*Fourier analysis, soft tissue facial shape, sexual dimorphism.*

I. Introduction

Physical appearance of individuals hasa major effect on personal confidence and social acceptance(1). Several factorseffecton esthetic demands such as culture, personal character, ethnicity and age(2). Rather than occlusal relationships, an overall improvement in facial estheticsis achieved after orthodontic treatment(3),so it is necessary to determine facial soft tissue paradigm.Previous investigations assessed facial shape based on radiographyand photogrammetry, reduced risk of X ray exposure is a prominent advantage of the latter.

A little is known about the soft tissue paradigm in different population. The size and form of facial shape can be affected by age, gender and skeletal malocclusion(4). Cephalommetry provides a relatively simple method to trace shape modification but it is not considered as a proper technique because it does not analyses the configuration entirely. Precise geometrics analyze variations of the facial form(5). Homologous andmarginal landmarks can be used to evaluate craniofacial form. Homologous landmarks are true anatomical landmarks, while marginal landmarks are achievedby geometrical calculating anatomical landmarks,both are helpful in reconstructionof morphological characteristics and evaluation of shapemodification through time. In this method, complex facial measurements are converted to sine and cosine functions and analyze as Fourrier's series.

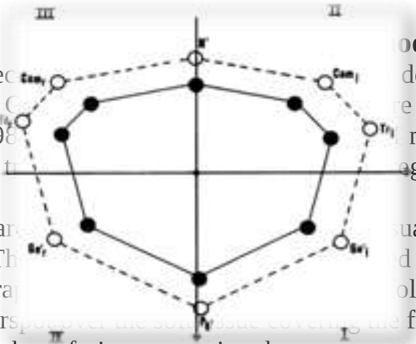
Craniofacial landmarks are prone to change with growth and development; hence, marginal landmarks may be used to analyze the overall shape of an individual irrespective of its size, spatial position or its relation with the reference planes(5).

Lu et al. (1965) and Lestrelet al. (1977) used Fourier analysis to reconstruct the facial outline form and to compare the differences among different populations(6, 7).

This method was later used by Ferrarioet al. (1995) as a computerized version to analyze soft tissue profile variations in adults among different genders(5).

One of the confounding factors in shape analysis is the size (dimensions) and thus should be standardized in analytical research. Standardization is performed either locally for individual samplesby dividing them by the maximum value or subtracting from the mean value, or by means of general approaches which involves a larger number of samples divided bya constant. In two dimensional regular shapes and three dimensional irregular shapes (e.g. face), perimeter and area are respectively referred to as standard indices (6-8).

The purpose of this study was to analyze the frontal view of the facial soft tissue in normal adults using photogrammetric imaging. Marginal landmarks were used to reconstruct the facial outline form and then Fourier analysis was used to evaluate differences among genders.



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A descriptive cross sec dental students (35 women and 30 men) of Ghazvin School of Dentistry, e selected according to normal dentofacial standards (Scheidemanet al. 19 molar relationship, absence of anterior and lateral crossbite, no history of gion, orthodontic treatment or craniofacial abnormalities.

The location of standar ual and tactile examination with a precision of 0.1 mm using a black pen. Th d by special markers (tip diameter of 8 mm) to enhance visibility in photogra ollowing soft tissue landmarks were used.

N´: the most prominent/anteriors frontonasal suture.
Pog´: the most anterior spot on the soft tissue covering the mentum on midsagittal plane (9).
Tr´: a cartilagenous prominence anterior to the external auditory meatus(9)
Canth´: the corner of the eye where upper and lower eyelids meet(5)
Go´: The most lateral portion of the mandible and the most inferior portion of the ramus(9, 10).
Tr´ and Go´ are two landmarks which are not easily determined in conventional photographic methods and therefore, stereophotogrammetry is used along with the relevant analytical software to locate these landmarks (Fig. 1). In this method, three digital cameras (A_4 Tech, Shuttle) were used. The distance between camera lenses were 5cm. the central camera was aligned with the midline of the chair/stool and the base of the camera. The other two cameras were subsequently located parallel to the central camera. The distance between the posterior leg of the stool and the posterior leg of the base of the camera was 127 cm. a longitudinal mirror (70cm×100cm) was placed in front of each subject anda blue background was designed for each photo. A software was designed to save all three photos in coordination with each other and available for analysis as one whole complex. Each photograph was obtained/taken in high NHP conditions with high repeatability and subsequently saved in bmp format (1, 11-13). The subjects were asked to take a few steps prior to sitting on the stool with feet touching the floor and then stare at their pupils in the mirror.

Fig. 1- ammetry

X and Y axes were drawn on each photograph from N-Pog landmarks and the two canthus landmarks respectively. The X-Y coordinates of each landmark was determined by the computer. Head rotations could be corrected by the software at this stage in a way that if the head was rotated +α degrees to the left, the software would turn it to the opposite direction to the same extent.

A line was drawn to connect the landmarkson each photograph rendering a closed contour. The photographs were standardized using identical pixel area (2500 pixel).The center of gravity was subsequently determined for each shape and adapted on the center of the X-Y axes. 360 vectors were drawn from the center of gravity counterclockwise which ultimately resulted in depiction of the face (Fig. 2). Each vector was defined by its length (modulus) and angle.

Fig.2- the closedcontour of the face obtained by connecting the adjacent landmarks

The coordinates of steep and length of each vector with respect to the horizontal axis formed a curve on Cartezian scale f(x,y) in which xand y indicate the length (modulus) and steep of each vector (Fig 3). This method resembled those of Halazonetis et al (1991)(3), Ferrarioet al. and Lestrelet al. (1997)(4, 6) with a slight difference that in this study, all these stages weredone automatically with minimal error and less time.

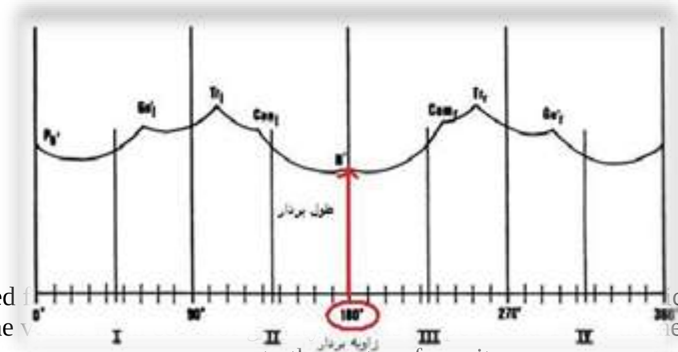

Fig 3- Reconstructed ... cal line indicatesthe modulus or the distance of the ... earest and farthest landmarks to the center of gravity.

In this stage, the software performs Fourier analysis with 360 series of rotation. The mathematical description of Fourier series is provided in the appendix. The formula was extended until the first twenty series and the succeedingseries were disregarded due to high decimals. The Sine (b_n), cosine (a_n) and domain (c_n) coefficients for the first twenty seriesof Fourier series were calculated for each photograph and the face shapes were reconstructed (Fig 4, 5).

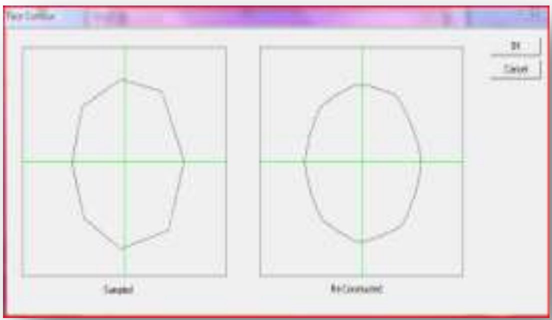

Fig.4- Facial shape contour

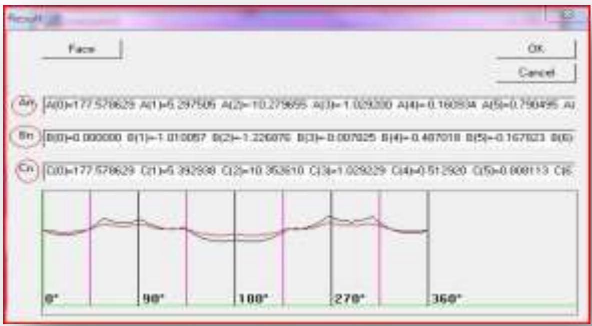

Fig.5- Results

Data were submitted to SPSS software for statistical analysis using T-test, correlation and regression analytical tests.

Ethical considerations:

In order to preserve the identity of each subject, their eyes were faded and the photographs were taken after obtaining informed consent. The photographs were archived in the school's data bank to maintain confidentiality.

III. Results

The Kolmogrov-Smirnov test indicated normal distribution of data among samples (P>0.05). Paired sample t-test revealed 99% correlation between the original and the reconstructed figure (P<0.005). Nonetheless, the mean values differed significantly between the original and the reconstructed curves (P<0.05).

The results failed to show any correlation between sine (b_n) and cosine (a_n) coefficients, hence none could be used independently to reconstruct the facial shape using Fourier analysis(6, 8). On the other hand, some $a_n$and some b_n coefficients were correlated with their peers in class I malocclusion test analyzed the mean (±SD) values for Fourier coefficients among sexes. Some coefficients i.e. b_n، 3 b4، $b_{9,}b_{10}$، b_{12}،b_{15}, b_{16}، c_{10}، c_{19} varied significantly in terms of gender between men and women (P<0.05) [table1].

Table 1- Mean (SD) coefficients by gender

variable	Male		Female		P-value
	number	Mean ± SD	number	Mean ± SD	
b_3	30	0.36±0.63	35	0.02 ± o.9	< 0.05
b_4	30	0.267±0.524	35	0.014 ±0.476	< 0.05
b_9	30	0.148±0.362	35	0.092 ± 0.412	< 0.05
b_{10}	30	0.11±0.247	35	0.089 ± 0.387	< 0.05
b_{12}	30	0.043±0.144	35	0.38 ± 0.174	< 0.05
b_{15}	30	0.078±0.128	35	0.005 ± 0.123	< 0.05
b_{16}	30	0.081±0.177	35	0.03 ± 0.181	< 0.05
c_{10}	30	0.175±0.255	35	0.646 ± 0.267	< 0.05
c_{19}	30	0.209±0.120	35	0.274 ± 0.124	< 0.05

Table 2- mean a,b,c Fourier coefficients among genders

Variable	Male	Female	P-value
	Mean ± SD	Mean ± SD	
Meana_n	9.48 ± 0.25	9.38 ± 0.29	< 0.05
Meanb_n	0 ± 0.06	0 ± 0.06	< 0.05
Meanc_n	8.84 ± 0.04	8.84 ± 0.04	< 0.05

There were no significant differences in the mean coefficients of a_n ، $b_n$and c_n among men and women [table 2]

IV. Discussion

In this study, a new approach i.e. Fourier analysis was used to reconstruct facial soft tissue contours as described thoroughly in the previous sections. Lu (1965), Ferrario (1995) and Lestrel (1997) had previously used this method, however, the present study was superior to those in that the analysis was done using a computer software (5-7). This study evaluated the effect ofgender on the soft tissue contour and their correlation with Fourier series coefficient in normal adults with class I malocclusion.

In this study, the correlation between S and R curves were 99% which were consistent with Ferrario's finding in 1995. The minimal correlation coefficient in the first twenty sentences of Fourier series in Lu's study was 0.6(7). Hence, the correlation of 0.9 retrieved in the present study was acceptable compared to Lue'svalue. One of the advantages of the classic Fourier's series is the geometrical meaning of harmonious coefficient. The differences in the Fourier coefficients are due to morphological variations (5)in a way that the cosine coefficient of$a_0$stands for the size of one form which having been standardized, is similar for all samples. The first sentence is a circle which is shifted toward the maximal area so that it solely depicts the overall facial shape and fails to render details of the shape. As sentences are further added, more details are incorporated in the picture(7). Although size (dimension) is a confounding factor in morphological analysis, yet the majority of analysis are conducted on people with significant differences in dimensions/size; hence morphological differences would not be evaluated(5). Fourier analysis can yield a separate evaluation of the effect of size and shape on morphology by amending size differences(5). Since conventional metric methods fail to analyze the roles of size and shape independently, the sizes were ranged to moderate the differences. This method (i.e. ranging) was not useful enough and its interpretation was difficult(5). Form differences/variations are generally determined by de nevo indices(e.g. width: length ratio) which is a combination of different metric techniques(5). Fourier analysis demonstrates the overall contour of a shape and since normalized coefficients of Fourier are constant in terms of direction, quantity/size and location,a true analysis would be achieved/performed (5). In the present study, the size was standardized among all photos with a constant coefficient (25000 pixels). Ferrario (1995) performed a similar method of standardization, however, they used analogous imaging with the unit of millimeter square and the constant point was 5000(6). In the present study, the vertical axis is compatible with the midsagital plane of the face which resembled Ferrario's and Lu's study(5, 7).

Greater number of landmarks can be used in the Fourier approach to yield a more precise contour of the face. However, calculations are independent from the number of landmarks. Biological issues such as identification of the landmarks may be the only shortcoming of this method(5, 7). Lu and Ferrario calculated a correlation coefficient of 0.6 and 0.99 between the S and R curves respectively. The 99% correlation coefficient retrieved in the present study, was indicative of adequate number of landmarks compared to Lu’s value as the minimal acceptable coefficient(5).

No significant differences were observed in the facial form of the samples in terms of gender and the mean coefficients of a_n ‘ $b_n$and$c_n$were similar among men and women. This finding was in agreement with Ferrario’s in 1995who presented similar results in terms of the correlation between gender and facial form, however, it differed from numerous other two-dimensional and conventional metric analytical studies which revealed sexual dimorphism(3-5, 12, 14-20). VFF et al. (1995) had earlier concluded that facial form is affected by age, sex and to a less extent, skeletal classification(15). Two reasons explain this difference between our finding and other two dimensional evaluations; those studies used conventional metric measures and failed to imply comprehensive statistical methods to analyze the results (5, 12, 14-21)Technique of photography and landmark spotting on the photographs are two errors which may occur in two dimensional photographic and radiographic imaging techniques.

Two dimensional frontal plane evaluations are not based on true landmarks because they fail to manipulate head rotations in this technique. To overcome this problem, we marked the true location of the landmarks on each subject’s face on the frontal plane (5). In general, two and three dimensional metric techniques are not comparable even though they imply similar landmarks under similar circumstances.

Appendix:
N: Harmony sentences
a_n: Cosine coefficient
b_n: Sine coefficient
τ: Normalized length/modulus of profile
Θ = π/τ

$$f(x) = \frac{a_0}{2} + \sum_{n=1}^{20}(a_n \cos \theta nx + b_n \sin \theta nx)$$

$$f(x) = \frac{a_0}{2} + \sum_{n=1}^{20}[c_n \, \mathrm{Cos}(\theta nx + \phi_n)]$$

In the following equations, $c_n$is the domain and φ_n is the phase of harmony sentences:

$$c_n = \sqrt{(a_n{}^2 + b_n{}^2)}$$

$$\varphi_n = \arctan(\frac{b_n}{a_n})$$

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